

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE	3. REPORT TYPE AND DATES COVERED FINAL/15 JAN 92 TO 14 JAN 95	
4. TITLE AND SUBTITLE FEATURE EXTRACTION BY BEST-BASIS AND WAVELET METHODS			5. FUNDING NUMBERS	
6. AUTHOR(S) M. V. WICKERHAUSER, G. L. WEISS AND R. R. COIFMAN			2304/ES F49620-92-J-0106	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) DEPARTMENT OF MATHEMATICS WASHINGTON UNIVERSITY ST. LOUIS, MISSOURI 63130			AFOSR-TR-95 0654	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NM 110 DUNCAN AVE, SUTE B115 BOLLING AFB DC 20332-0001			10. SPONSORING / MONITORING AGENCY REPORT NUMBER F49620-92-J-0106	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) In the past year, support from this contract has been acknowledged in 14 published articles and one book. New characterizations of wavelets have been found leading to new constructions and new wavelets. Advances were made in the theory of multipliers in Fourier analysis. Wavelet technology was transferred to four commerical products: liquid crystal matrix display driver simulation, de-noising software for medical images, image compression algorithms for the FBI, and image analysis software for automatic finger print identification systems from compress images. One book and seven technical reports on new algorithms have been submitted or are in preparation. One patent was issued, US No. 5,384,725, "Method and Apparatus for Encoding and Decoding Using Wavelet Packets" (R. R. Coifman, Y. Meyer, M. V. Wickerhauser). An improve version (AWA 3.0) of and earlier commerical software package, the "Adapted Wavelet analysis Library", was released. Travel funds supported about one dozen seminars, colloquia and minicourses in Australia, Croatia, France, Germany, Italy, Spain and the United States.				
14. SUBJECT TERMS			15. NUMBER OF PAGES	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR(SAME AS REPORT)	



19951017 032

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Research results. In the past year, support from AFOSR Research Contract F 49620-92-J-0106, "Feature Detection with Wavelet Packets," has resulted in the following acknowledged work:

In 1994, 15 journal articles or book chapters plus one advanced textbook, listed in the bibliography below, acknowledged partially support by AFOSR. Wavelet technology has been transferred to three commercial and government products:

- wavelet decomposition and synthesis software for simulating new methods of driving flat panel matrix displays such as LCDs;
- de-noising software for cleaning up medical images;
- image compression algorithms used by the FBI in their WSQ fingerprint image compression standard;
- image analysis software for designing new and faster automatic fingerprint identification systems from compressed images.

So far in 1995, AFOSR support resulted in one book chapter, one journal article, and two technical reports on new algorithms suggested by previous results:

- a method for quickly computing tables for multiplying functions superposed from just a few wavelets, which give good approximations to vorticity fields in fully-developed turbulence;
- a method for rapidly computing the rate-distortion curve produced by transform coding image compression, which can then be used to set the quantization to get a target compression ratio.

US Patent No. 5,384,725, "Method and Apparatus for Encoding and Decoding Using Wavelet Packets," was granted to R. R. Coifman, Y. Meyer, and M. V. Wickerhauser. An improved version (AWA 3.0) of an earlier commercial software package, the "Adapted Wavelet Analysis Library," was released.

Considerable progress was achieved by Weiss, X. Fang, E. Hernández and X. Wang in characterizing minimally supported frequency wavelets. Weiss, A. Bonami, S. Durand and F. Soria found a geometric construction of Lemarié-Meyer wavelets from Shannon and Daubechies wavelets. These results advance the program of finding constructions of all orthonormal wavelets bases. In fact, the various constructions obtained have produced new classes of wavelets.

Weiss, E. Berkson, M. Paluszynski and A. Založnik found a new formulation of the theory of transference which has important applications to the theory of multipliers in Fourier analysis.

Travel support in the past year has funded a score of seminars, colloquia and minicourses in Australia, Croatia, France, Germany, Italy, Spain, and throughout the United States, and resulted in new and continuing collaborations with researchers in those places.

Technology transfers. AFOSR sponsored research has produced the following transitions to commercial and government industrial technologies:

- A software package "Graphical Work Station" (GWS) was written by M. V. Wickerhauser, R. R. Coifman and K. Ukraincik (of Digital Diagnostics Corporation) for Positive Technologies, Inc. That company is working to implement "adaptive scanning" pixel driver algorithms for twisted nematic passive matrix liquid crystal displays (TN-LCDs). The use of adapted wavelet transforms allows larger or higher-resolution TN-LCD screens (more rows and columns) without the loss of contrast that occurs with the traditional Alt-Pleshko line-at-a-time driving method. Source codes descendent from AFOSR-sponsored research software (WPLW and AWA 2.0) are the basis for both display simulation and preprocessing for actual display driving. Positive Technologies, Inc. has invested approximately \$200,000 and ARPA has supplied an additional \$900,000 to develop 3 prototype TN-LCD development workstations.
- A software package "denoise" was built from AWA 2.0 for Numerics Medical Imaging, Inc., a startup company in Connecticut which supplies software to remove speckle and distortion from echo-planar magnetic resonance tomographic images (EP-MRIs). The software finds a best-adapted wavelet packet decomposition of a sequence

of EP-MRIs by minimizing an information cost functional, then discards the signal portion with high cost but low energy. The retained portion has a dramatically greater signal-to-noise ratio and allows the diagnosing physician to see small features, such as arterial blockages, which were masked by the noise in the original. Numerics Medical Imaging, Inc. has invested approximately \$100,000 in software development for this package.

- The FBI Automatic Fingerprint Identification System (AFIS) project decided to fund Martin-Marietta (MM) corporation to develop new algorithms to search a WSQ-coded database of fingerprint images. M. V. Wickerhauser completed a \$17,000 contract with MM to supply software for feature extraction from WSQ and wavelet coefficients. That software will in one form or another be used in the large integrated system that MM has contracted to deliver.

Sample publications.

1. Patent: "Method for Encoding and Decoding Using Wavelet Packets" (Coifman, Meyer and Wickerhauser) Patent Number 5,384,725. Issued January, 1995
2. Software: "Adapted Wavelet Analysis Library" (Wickerhauser), Version 3.0, June, 1995.
3. Preprint: "A Relation between Shannon-Weaver entropy and 'theoretical dimension' for classes of smooth functions" (Trgo and Wickerhauser), May, 1995. To appear.
4. Preprint: "Multiplication of short wavelet series using connection coefficients" (Perrier and Wickerhauser), April, 1995. To appear.
5. Article: "Experiments with Adapted Wavelet De-Noising for Medical Signals and Images" (Coifman and Wickerhauser), in Time-Frequency and Wavelets in Biomedical Engineering (Metin Akay, ed.), IEEE Press, Piscataway, New Jersey, 1995
6. Article: "Wavelets and Time-Frequency Analysis" (Hess-Nielsen and Wickerhauser) Proceedings of the IEEE, 1995. To appear.
7. Book: Adapted Wavelet Analysis from Theory to Software (Wickerhauser) AK Peters, Ltd., Wellesley, MA, 1994.
8. Article: "Smooth Localized Orthonormal Bases" (Wickerhauser) in Proceedings of the Sixth Annual Conference of the National Alliance of Research Centers of Excellence (Alfred Z. Msezane and Katrina L. Barnum, eds.) Clark Atlanta University, Atlanta, Georgia, 1994.
9. Article: "Comparison of picture compression methods: Wavelet, wavelet packet, and local cosine transform coding" (Wickerhauser), in Wavelets: Theory, Algorithms, and Applications (ed. C.K.Chui), Academic Press, San Diego, CA, September, 1994.
10. Article: "Efficiency Comparison of Wavelet Packet and Adapted Local Cosine Bases for Compression of a Two-dimensional Turbulent Flow" (Wickerhauser, Farge, Goirand, Wesfreid and Cubillo, in Wavelets: Theory, Algorithms, and Applications (ed. C.K.Chui), Academic Press, San Diego, CA, September, 1994.
11. Article: "Adapted Waveform Analysis as a Tool for Modeling, Feature Extraction, and Denoising" (Coifman and Wickerhauser), Optical Engineering 33(1994),2170-2174.
12. Article: "Two Fast Approximate Wavelet Algorithms for Image Processing, Classification, and Recognition" (Wickerhauser), Optical Engineering 33(1994),2225-2235
13. Article: "Large-rank Approximate Principal Component Analysis with Wavelets for Signal Feature Discrimination and the Inversion of Complicated Maps" (Wickerhauser), Journal of Chemical Information and Computer Science 34(1994)

14. Article: "A Parallel Two Dimensional Wavelet Packet Transform and Its Application to Matrix-Vector Multiplication" (Goirand, Wickerhauser and Farge), in Wavelets Applications in Chemical Engineering (ed. R. L. Motard and B. Joseph), Kluwer Academic Publishers, Norwell, MA, 1994.
15. Article: "An Adapted Waveform Functional Calculus" (Wickerhauser) in Proceedings of the Cornelius Lanczos Centenary, SIAM Press, Philadelphia, PA, September, 1994.
16. Article: "Traitement de la Parole par Ondelettes de Malvar" (Wesfreid and Wickerhauser), in Reconnaissance Automatique de la Parole (J.P.Haton, ed.) CRIN/INRIA, Nancy, France, 1994.
17. Article: "Time Localization Techniques for Wavelet Transforms" (Wickerhauser), in Automatic Systems for the Identification and Inspection of Humans (Richard J. Mammone and J. David Murley Jr, eds.), SPIE Proceedings 2277, 1994.
18. Article: "Function spaces on spaces of homogeneous type" (Weiss and Han), Essays on Harmonic Analysis in Honor of E. M. Stein, Princeton Math Series No. 42, 1995
19. Preprint: "A new atomic decomposition for the Triebel-Lizorkin spaces" (Weiss and Han), Proceedings of the 1994 Caracas Conference in honor of M. Cotlar, Academic Press, 1995.
20. Article: "Transference couples and their application to convolution operators and maximal operators" (with Berkson and Paluszynski), Proceedings of the conference in Functional Analysis, Harmonic Analysis and Probability, U. Missouri, May 30-June 3, 1994 (AMS Proceedings; N. Kalton and E. Saab, eds).
21. Preprint: "Wavelets obtained by continuous deformations of the Haar wavelet" (Weiss, Bonami and Durand), 1995, to appear in *Rev. mat. iberoamericana*.
22. Preprint: "Transference of multilinear operators" (Weiss and Grafakos), 1995, to appear in *Illinois J. Math.*
23. Preprint: Smoothing minimally supported frequency (MSF) wavelets, Part I" (Weiss, Hernández and Wang), 1995, to appear in *J. Fourier Anal. Appl.*
24. Preprint: Smoothing minimally supported frequency (MSF) wavelets, Part II" (Weiss, Hernández and Wang), 1995, to appear in *J. Fourier Anal. Appl.*
25. Book: "A First Course in Wavelets" (Weiss and Hernández), 1995, to be published by CRC Press.

Co-workers. Faculty: Y. Meyer, M. Farge, C. D'Alessandro, P. Auscher, M. Holschneider, A. Bonami, F. Soria, B. Torresani, A. Grossmann, E. Hernandez, .

Postdocs: X. Fang, N. Hess-Nielsen, F. Pascal, E. Wesfreid, A. Trgo, V. Perrier

Graduate Students: X. Wang, S. Tourville, S. Littlewood, E. Goirand

Professional Honors.

- G. L. Weiss: Chauvenet Prize, 1968; Honorary Doctorates from Beijing, Barcelona, and Milan.
- Y. Meyer: Legion d'Honneur, 1992. Prof. Universitaire, 1992.
- Marie Farge: Cray Prize, 1988.
- E. Goirand: IBM Parallel Algorithms prize, 1993.

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